Urban Forestry & Urban Greening 44 (2019) 126389

Contents lists available at ScienceDirect

Urban Forestry & Urban Greening

journal homepage: www.elsevier.com/locate/ufug

Feasibility assessment of rooftop greenhouses in Latin America. The case study of a social neighborhood in Quito, Ecuador

Ana Nadal[a,*,1], Daniel Rodríguez-Cadena[a,1], Oriol Pons[b], Eva Cuerva[c], Alejandro Josa[d,e], Joan Rieradevall[a,f]

[a] Sostenipra Research Group (SGR 01412), Institute of Environmental Sciences and Technology (ICTA), Z Building, Universitat Autònoma de Barcelona (UAB), Campus UAB, 08193, Bellaterra, Barcelona, Spain

[b] Department of Architectural Technology I, School of Architecture (ETSAB), Universitat Politècnica de Catalunya (UPC-Barcelona Tech), Avinguda Diagonal 649, 08028, Barcelona, Spain

[c] Department of Projects and Construction Engineering (DEPC), Universitat Politècnica de Catalunya BarcelonaTech. Diagonal 647, Ed. H, 08028, Barcelona, Spain

[d] Department of Civil and Environmental Engineering (DECA), Universitat Politècnica de Catalunya (UPC-BarcelonaTech), Campus Nord, C/Jordi Girona 1-3, 08034, Barcelona, Spain

[e] Institute for Sustainability Science and Technology (IS.UPC), Universitat Politècnica de Catalunya (UPC-BarcelonaTech), Campus Nord, C/Jordi Girona 31, 08034, Barcelona, Spain

[f] Department of Chemical, Biological and Environmental Engineering, Universitat Autònoma de Barcelona (UAB), Campus UAB, 08193, Bellaterra, Barcelona, Spain

A R T I C L E I N F O

Handling Editor: Cynnamon Dobbs

Keywords:
Urban agriculture
Hydroponic
Sustainable cities
Food security
Food self-sufficiency
Rooftop greenhouse

A B S T R A C T

Today, food security has a critical place in the government agendas of developing countries. In Latin American case, urban contexts have been subject to radical transformations in the last decades, most apparently through the expansion of social housing, which may limit or condition access to food for the neediest population. Nowadays, in Latin America, there are numerous cases of urban agriculture. Quito (Ecuador) stands out for the development of urban agriculture through the Participatory Urban Agriculture Project - AGRUPAR; initiative that has led to the implementation of orchards with organic production, raising of small animals, food processing and marketing of surpluses for food-nutrition security. Above all, it has transcended its urban and peri-urban intervention to rural areas, favoring the urban-rural connection. Also, worldwide the urban agriculture is developed in different forms, one of which is through crops protected by a greenhouse on the roofs: Rooftop greenhouse (RTG). This form of UA uses specific substrates for hydroponic crops and has modern irrigation systems often combined with rainwater harvesting and provides a unique opportunity to improve urban agriculture in Quito.

The purpose of this study is to identify the implementation potential of rooftop greenhouses in social neighborhoods in Quito. Standard methods to assess the potential use of rooftop greenhouses were adapted to a social neighborhood. The guidelines follow three steps: Step 1: Characterization based on criteria; Step 2: Available surface determination and Step 3: Production, self-sufficiency and self-supply. “La Comuna Santa Clara de San Millán” was selected as study area. The results showed that 33.2% (7.70 ha) of the neighborhood rooftops had a short-term feasibility to install rooftop greenhouses, with the potential to produce 1,579,140 and 56,720 kg/year of tomato and lettuce respectively. The research has developed reliable guidelines that prove the feasibility to install rooftop greenhouses in similar large Latin-American cities area.

1. Introduction. Participatory Urban Agriculture

Today, urban agriculture (UA) emerges as a tool to mitigate and prevent the negative effects on food flows caused by a quick urbanization process(Halloran, 2011; Wadel et al., 2010; Willett et al., 2019) and is gaining support as an important part of the solution

ABBREVIATIONS: AGROCALIDAD, Agriculture Ministry Agency; CSCSM, Comuna Santa Clara de San Millán; DMQ, Metropolitan District of Quito; AGRUPAR, Participatory Urban Agriculture Project; RC, Reinforced concrete; RTG, Rooftop greenhouse; UA, Urban agriculture

* Corresponding author at: Edifici ICTA-ICP, Carrer de les Columnes, 08193, Bellaterra, Barcelona, Spain.

E-mail addresses: ana.nadal@uab.cat, ana.nadal.fuentes@gmail.com (A. Nadal), danielo_66@hotmail.com (D. Rodríguez-Cadena), oriol.pons@upc.edu (O. Pons), eva.cuerva@upc.edu (E. Cuerva), alejandro.josa@upc.edu (A. Josa), Joan.Rieradevall@uab.cat (J. Rieradevall).

[1] Ana Nadal and Daniel Rodríguez-Cadena contributed equally to this paper and share first authorship.

https://doi.org/10.1016/j.ufug.2019.126389
Received 27 November 2018; Received in revised form 10 May 2019; Accepted 8 July 2019
Available online 20 July 2019

(Despommier, 2011; Maxwell, 2000; Maxwell et al., 1999; Orsini et al., 2013; RUAF Foundation, 2015; Zezza and Tasciotti, 2010). Urban agriculture is developed in different forms, one of which is through crops protected by a greenhouse on the roofs: Rooftop greenhouse (RTG) (Nadal et al., 2015; Sanjuan-Delmás et al., 2018). This form of UA can use hydroponic systems providing temperature control, reducing evaporative water loss, preventing control of disease and pest infections, and protecting against the changing weather(Montero et al., 2017; Ana Nadal et al., 2017; Pons et al., 2015). Hydroponic systems a soilless technology, are more efficient than other soil systems, is the fastest growing and second generation of crop production system in agricultural industry.

Hydroponic systems include this benefits: reduce water consumption, use liquid nutrients wich is recirculating all over the system, no nutrient waste due to water runoff, irrigation water is supplied directly to root areas, efficient use of fertilizers and cost saving, achieving up to five times more productivity in less space due to reducing substrate use, lightining and reducing the crop weight and therefore their loads on the building structure (Dubbeling and Massonneau, 2014; Sanyé-Mengual et al., 2015a, 2015b; Chow, Y. N et al, 2017).

In some high densely populated cities, where soil availability is limited, RTGs has been installed for vegetable production (Baker, 2000; Germer et al., 2011; Montero et al., 2017; Peng and Jim, 2013; Tian et al., 2012). As an example in developed countries, in New York, Gotham Green has 1400 m^2 of RTGs and aims to reach 18,000 m^2 and The Vinegar Factory produces its own vegetables and fruits in 830 m^2 of RTGs. In Montreal, Canada, Lufa Farms has built 2900 m^2 of RTGs (Sanyé-Mengual et al., 2015a). There are also interesting experimental experiences. For example on the rooftop of ICTA-ICP (Environmental Cience and Technology Institute and Catalonian Paleontology Institute) building at the Autonomous University of Barcelona, there is an integrated RTG in which CO_2, energy and water connected flows between the RTG and the building are studied so they can improve the edifice metabolism (A. Nadal et al., 2017b)

In this sense, Latin-American countries such as Argentina, Brazil and Cuba have approved policies and programs to promote UA (Moran-Alonso, 2011; Moran-Alonso and Hernandez, 2011; Orsini et al., 2013; Rojas, 2016).There are also several examples of UA as an initiative led by local governments, organizations and multilateral organisms (mostly FAO), which aim to encourage involvement from the unemployed and socially excluded population, in order to improve their socio-economic conditions, malnutrition and confront famine(Baudoin et al., 2013; Cerón-Palma et al., 2012; Colinas et al., 2018; De la Sota et al., 2018; FAO, 2014a; Hou and Grohmann, 2018; La Rosa et al., 2014; Nastran et al., 2019; Orsini et al., 2014).

A real example is La Habana, Cuba, which uses 12% of its surface area for UA, to grow organic crops mainly for self-consumption (Cruz and Sánchez-Medina, 2003). There are also further cases of UA in Latin-American cities (Table 1).

Ecuador is widely recognized for its socially focused UA system. In April of 2000, the Quito Declaration took place in Ecuador, which was signed by representatives of 27 cities in 10 Latin-American and Caribbean countries, with a commitment to develop and promote UA in the region (FAO, 2014b, 2012). These UA developments were based on the urban-architectonic features shared by cities in this region, with free and horizontal roofs. On an urban scale the extensive use of UA in Quito is remarkable (CONQUITO, 2009; FAO, 2014b).

Specifically, the city of Quito stands out for the development of the Participatory Urban Agriculture Project - AGRUPAR; a program that promotes self-production of food as a strategy of contribution to food-nutrition security(CONQUITO, 2009). This project has allowed the increase of biodiversity, the recovery of public and private spaces for productive purposes, allowing access to healthy food for the entire population. The above, through the implementation of orchards with organic production, raising of small animals, food processing, and surplus marketing. The urban agriculture project has transcended its urban and peri-urban intervention to rural areas of the urban district, favoring the urban-rural connection, within the City-region approach. In addition, AGRUPAR has promoted the accession of Quito to the Pact of Food Policies of Milan(CONQUITO, 2009).

Additionally, most people in Latin America live in single family houses(Gilbert, 2011). In this sense, the growth of Latin American cities is linked to the construction of social housing neighborhoods; however, and according to Nieto (1999), the housing deficit of the region has increased year after year. Millions of Latin American families live in unfinished homes since the construction of houses tends to develop gradually and depends on the income of each family(Gilbert, 2011). Despite the construction by stages, the houses are usually built with resistant materials(Cerón-Palma et al., 2013), since socially housing is considered an asset to the economy of families(Gilbert, 2011). Therefore, this type of building has minimum requirements that allows the use of roofs and other spaces for the implementation of vertical urban agriculture (A. Nadal et al., 2017a, Nadal et al., 2018).

In this sense, the present research aims to identify the implementation potential of rooftop greenhouses in social neighborhoods in Quito. To do so it develops a new version of a previous guideline through an interdisciplinary scope, which was applied in a neighborhood selected for the research. This article has the 3 following specific objectives: 1) carry out research about existing guidelines for installing RTGs to take relevant cases that could be useful in Latin-American cities and adapt them to a series of guidelines for social Latin American neighborhoods; 2) In spite of the different types of cities in Latin America, we seek to identify a social neighborhood in Quito, Ecuador, as a case study with the most representative characteristics of Latin American cities to test this guide.; 3) determine the available surface area for a short-term use of RTGs, and then estimate the potential

Table 1
Urban Agriculture experiences in Latin America.

Country	City	Kind of orchard	Number of orchards	Production Ton/year	Urban Farmers	Beneficiaries	Reference
Argentina	Rosario	Household	–	–	1800	–	FAO, 2014
Brazil	Belo Horizonte	Household	233	–	–	–	FAO, 2014
Colombia	Bogotá	Household	–	–	10,000	8,500 Families	FAO, 2014
Antigua and Barbuda	Conglomerate of cities	Household	–	280	–	–	FAO, 2014
Cuba	La Habana	Household	–	6700	90,000	30,000 inhabitants	Liendo and Martínez, 2006; FAO, 2014
México	Ciudad De México	Household	12,300	–	–	–	Torres-Lima et al., 2010
Bolivia	El Alto	Household	–	–	–	89,000 inhabitants	FAO, 2014
Nicaragua	Conglomerate of cities	Household	250,000	–	–	–	FAO, 2014
Ecuador	Quito	Household	800	–	10,250	–	FAO, 2014
		Communitarian	140	–		–	
		Scholar	128	–		–	

results: production, self-sufficiency and the surface area needed to self-supply. This could allow to identify the potential of RTGs to achieve food security and social urban rehabilitation.

2. Background. Urban context and urban agriculture of Quito

The high rates of urbanization have led to the development of high concentrations, becoming the most urbanized region in the world after North America. Although the cities of Latin America are heterogeneous and there are different typologies; there are common challenges and problems(NU. CEPAL, 2013):

- High degree of urban primacy
- Urban growth disjointed in the periphery of cities
- High rates of socio-spatial segregation
- Cities with a monocentric development
- Absence of clear and efficient urban development policies that allow integral development

Of which, Quito presents the great majority of these characteristics. Other criteria were defined for its selection as a case study:

a) Socio-economic conditions
b) Technological level
c) Structural characteristics and local environmental context
d) Framework of an urban planning system

Quito represents the dominant center in Ecuador and presents socio-economic segregation, which accounts for important differences in vulnerability in different areas of the city. It presents an important growth in terms of land occupation, changing the use of soils in peri-urban areas. To delve into the subject, the main characteristics of Quito as a case study are presented below(NU. CEPAL, 2013).

The Metropolitan District of Quito (DMQ), has a 565 inhabitants per km^2 density and 3,8 inhabitants by home, considered as a disperse city, which is on the way of becoming a compact city due to new urban regulations, therefore, nowadays it is a mix of high density and low density areas located in differentiate areas (Correa, 2012; Jaramillo and Van Sluys, 2012). The same process of compaction is happening in other Latin-American cities (Garza, 2009). High density or compact cities are areas that are characterized by population concentration in buildings where several families live, on the other hand on a low density or disperse city, consists on single family households with neighborhoods with lower construction diversity (Chavoya et al., 2009).

There were three important phases during its urban configuration. First, during the first half of the 20th century, its growth focused on a North-South axis, generating an urban expansion process without precedent, based mainly on an important migration flux from rural areas (Clavijo, 2013) that consolidated the compact urbanization process of DMQ (Correa, 2012). Then, the second half of 20th century was characterized by an exponential urban growth in the valleys located at the East of DMQ that extended the boundaries of the city (Correa, 2012). Third, at the beginning of 21 st century, the new Metropolitan Land Use Plan for the DMQ 2012–2022 (PMOTDMQ) priorized vertical growth and city densification, leading to a second ongoing compaction process (Jaramillo and Van Sluys, 2012; MDMQ, 2012a; Vaca, 2015). These phases have defined the present mixed urban conformation, nonetheless, it is still mainly has a disperse configuration and therefore similar to most Latin-American cities (Garza, 2009; Quintero and Gómez, 2012). Therefore, studies and experiencies in Quito can be used as a reference for the region.

There are numerous DMQ particular conditions that make Quito specially suitable for UA experiences. For example the local building guidelines, the technical rules for architecture and urbanism, consider the residential agriculture as a land use (MDMQ, 2011). Quito's location and weather conditions also favor UA (Appendix A), with mid-high precipitation and stable temperatures throughout the year, and optimal sunlight hours for agriculture production (MDMQ, 2012a, 2012b). The demographics features (rural-urban migration) and architectural features of Quito also endorse UA, with a dense city with unfinished buildings (useless spaces with UA potential) located in peripheral areas (Correa, 2012; Figueroa, 2012).

In Quito the main construction material is reinforced concrete, roughly 75% of the households are build on this material and have unfinished rooftops (INEC, 2010). This is relevant for RTGs assessment and showed a potentiality to its implementation. Moreover, there are vulnerable sectors, in which there is a need for food security and access to acceptable food. This is fundamental for decision makers, whom require well planned methods to consider the use and installation of UA facilities, in particular RTGs, when the urban layout and architecture make this option feasible.

3. Methodology

3.1. Guideline adaptation

Existing guidelines for installing RTGs have been analyzed and an adaptation was made from two researchs developed in Barcelona by Sanyé-Mengual et al. (2015a, 2015b) and Nadal et al (2017a) and focused on several factors to determine the economic viability of installing RTGs. The guidelines follow three steps shown in Fig. 1.

Relevant aspects of the guidelines were used together with features that were developed for this research to define the proposed guidelines, presented in Table 2. These guidelines have been applied to analyze the feasibility of RTGs implementation in the study area.

- **Step 1: Characterization based on criteria**

The following three criteria were applied and adapted for this research: urban, agronomic and technical. Urban criteria include 2 aspects; the legal background, which considered a revision on rules,

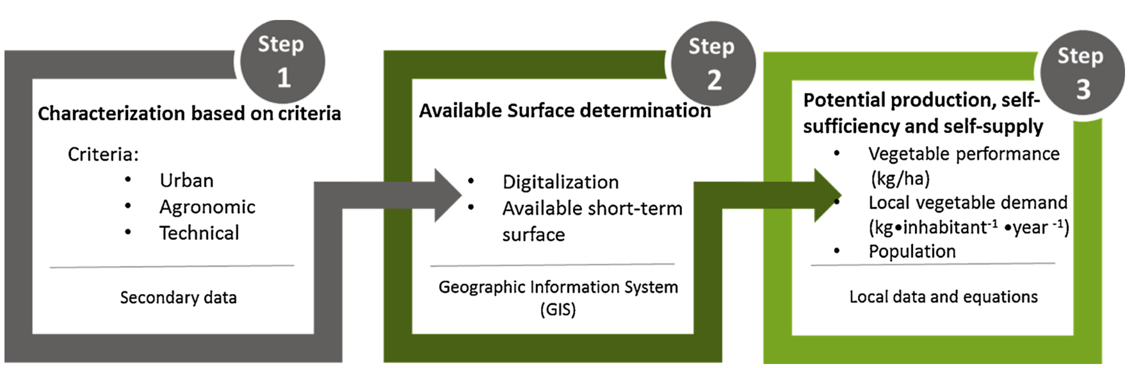
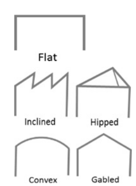


Fig. 1. Methodology diagram based in Sanye-Mengual et al., (2015) and Nadal (2017) guidelines.

Table 2
Graphical representation of the methodology (guide specifications) proposed for identifying the feasibility of RTG implementation in social neighborhood in Quito.

STEP 1		CRITERIA	ASPECT	REQUIREMENT	IMPLEMENTATION FEASABILITY Direct Short-term Digitalization: polygon	 Middle and long-term Digitalization: point	RESOURCES AND TOOLS
	CHARACTERIZATION BASED ON CRITERIA	Urban	Legal *	Rules, ordinances, development plans and other official local documentation.	X	X	Local official documentation. Websites of local institutions.**
			Roof top surface available	Covers > 10 m^2 **	X		Local cadastral plan, orthophoto.
				Free of occupation (Antennas, water tanks, water heaters, craft workshops)	X		GIS
		Agronomical	Social *	Agricultural Tradition and previous knowledge	X		Historical Documents and Data about rurality migraton living in the area, interviews**.
			Sunlight availability **	Minimum: 4-6 hours of sunlight	X	X	Local secondary information. NASA Surface meteorology and solar energy (web application)**
		Technical	Architectural *	Load Capacity	X	X	Orthophoto or site inspection. GIS
			Rooftop Material*	Reinforced concrete	X		Orthophoto or site inspection.
				Metal		X	GIS
				Asbestos		X	
				Zinc		X	
				Roof tile		X	
				Palm or straw		X	
			Slope*	Flat	X	X	Orthophoto or site inspection.
				Inclined		X	GIS
				Gabled		X	
				Hipped		X	
				Convex		X	
STEP 2	AVAILABLE SURFACE DETERMINATION	Middle & long term available surface			Rooftops were digitalized as polygons, to obtain available surfaces considering criteria defined on Step 1		
		Term available surface (ha)			Middle and Long-term implementation required an reconstruction to adapt the roof for an RTGs structure		
STEP 3	PRODUCTION, SELF-SUFFICIENCY & SELF-SUPPLY	Selected vegetables	$Production\ (kg/year) = Potential\ Area\,(ha)\cdot Vegetable\ output\left(\frac{kg}{ha \bullet year}\right)$ $Self-sufficiency\ (persons/year) = \frac{Production\,(kg)}{average\ vegetable\ intake\left(\frac{kg}{percapita\cdot año}\right)}$ $**\ Self-supply\ surface\ (ha) = \frac{average\ vegetable\ intake\left(\frac{kg}{percapita\cdot año}\right)*\text{population}}{Vegetable\ output\left(\frac{kg}{ha}\right)}$				

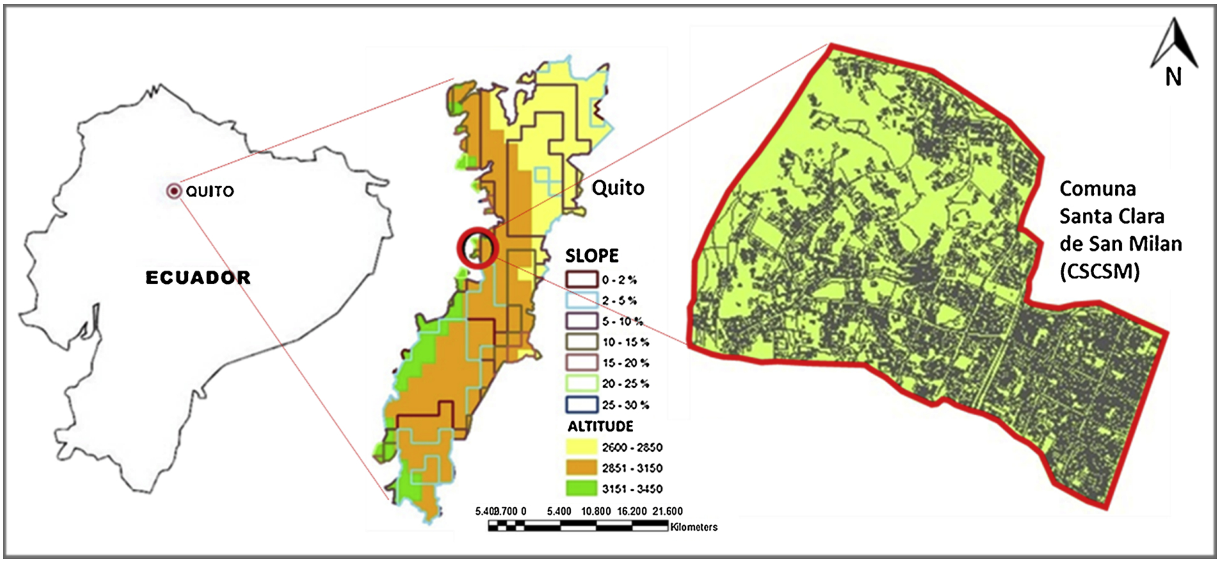


Fig. 2. Location of social neighborhood Comuna Santa Clara de San Millán.

ordinances, development plans, laws and other official documentation from the study area location, at local and national level, to determine conditions which could limit or enhance RTGs implementation. Also, environmental regulations on UA and RTGs were analyzed, and finally commercial regulations were checked and insititutional background is reviewed. The roof top surface available were analyzed as well, related with self-supply and food security at household level, which considers that the needed surface to produce enough vegetables for a family of four people is 10 m^2 (FAO, 2005; Jeavons and Cox, 2007), in this sense lower surfaces will be considered as not feasible. Besides, in order to facilitate RTGs implementation, it was determined that potential surfaces must be free of permanent equipment, like solar panels, climatization equipment, water tanks among others. Nonetheless, the surface can also be considered as feasible if this equipment can be removed.

Second, the Agronomiccriteria, here social aspects were including as an additional feature on the guidelines. The knowledge of a specific territory and population could be linked to agricultural capacities related to the rural migration to the cities, as well as the historical context of community. Settlements around the old town in cities used to have agricultural land use. On the other hand, the main factor which limit agricultural production is sunlight hours was considered because it is fundamental for vegetative growth and thus for RTGs implementation (shadows related of proximity buildings must be considered).

Third, the Technical criteria, architectural features were analyzed, the structural capacity of buildings is important to determine whether it would support an RTG on its rooftop, therefore, guidelines for buildings design, which show structural capacity and security regulations were researched. Feasibility clasification is based on rooftop construction materials (reinforced concrete, steel or timber structure and asbesto cement, zinc, roof tile, palm or straw finishing layers) and slope (flat, pitched, gabled or hipped roof).

- **Step 2: Available surface determination**

These considerations from Step 1 were used to separate short-term feasibility from middle and long-term feasible RTGs implementation. Geographical data analysis was made using ArcGis 10.2 (ESRI, 2013). It consisted in counting all buildings determined as middle and long term feasible, digitalizing them as a point, and measuring all short-term feasibility RTGs implementation, digitalizing them as polygons. The data source were orthophotos obtained from a project of Ecuadorian Agriculture Ministry of (SIGTIERRAS, 2016), and satellite pictures obtained from Google™Earth (Capture date: March16th, 2016).

- **Step 3: Production, self-sufficiency and self-supply**

Finally, production, self-sufficiency and self-supply were measured taking the surface results obtained for short-term feasibility implementation, two Eqs. (1)and (2) where obtained from an assessment for RTG feasibility (Sanyé-Mengual et al., 2015a), and the third equation was developed to measure self-supply capacity, to take into account the space needed to supply a determined population, which is relevant for this research. There were considered no difference between periods because the productivity in greenhouses remains similar all year in this region. The equations used were the following:

$$Production\ (kg/year) = Potential\ Area\,(ha)\cdot Vegetable\ output\left(\frac{kg}{ha\bullet year}\right) \tag{1}$$

$$Self-sufficiency\ (persons/year) = \frac{Production\,(kg)}{average\ vegetable\ intake\left(\frac{kg}{percapita\cdot año}\right)} \tag{2}$$

$$Self-supply\ surface\ (ha) = \frac{average\ vegetable\ intake\left(\frac{kg}{percapita\cdot año}\right)*\text{population}}{Vegetable\ output\left(\frac{kg}{ha}\right)} \tag{3}$$

There were chosen two highly demanded vegetables to use the equations, which avaraverage intake per year and output were obtained from secondary sources, in order to estimate the RTGs potential benefits that would be obtained through their implementation. It could use for any crop and could be analyzed with multicrop as well.

3.2. Methods: Application to a case study

3.2.1. Case study

The social neighborhood, “La Comuna Santa Clara de San Millán” (CSCSM) (Comuna: minor administrative subdivision corresponding to an urban, rural, or mixed area). was selected as study area (Appendix B).

The CSCSM it is located in Northwestern zone of Quito (Fig. 2), on the foothills of Pichincha Mountain, which limits its expansion. Regarding to services there are a coverage of potable water of 64%, sewage system 77%, electricity 99% and 38.1% finished roads (pavement, pavement cobble and concrete). Neighborhoods located next to

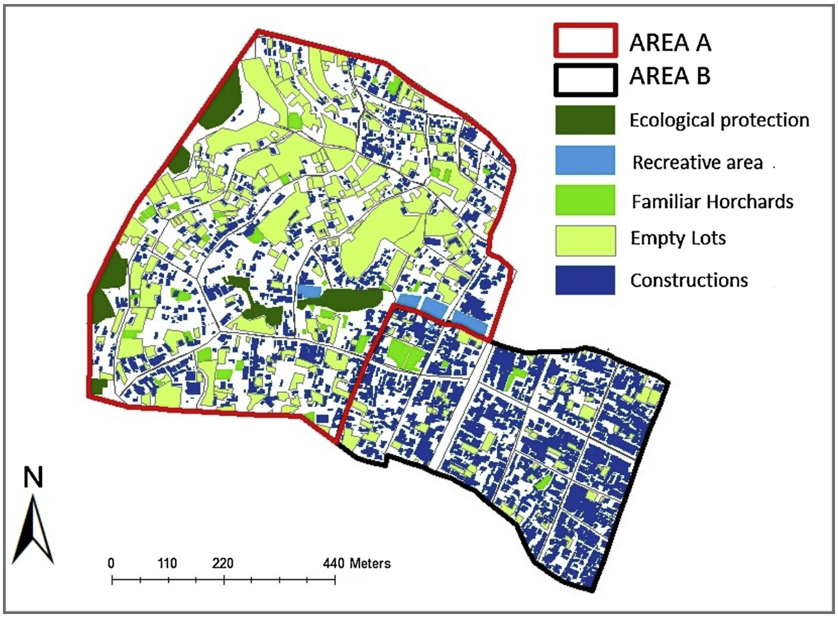


Fig. 3. Map of Comuna Santa Clara de San Millán, Land Use.

foothills present similar characteristics because of their similar topography and natural conditions (Carrión and Erazo, 2012). These neighborhoods also have the same structure than those located on peripherical rings, considered as disperse areas, that form the city (Jaramillo and Van Sluys, 2012), which made a portion of CSCSM also representative of this areas. To sumarize, this neigborhood has two different areas, which represent a compact and disperse (peri-urban) area respectively.

In order to improve the assessment of this study results and based on what was indicated by Schneider and Woodcock (2008), the CSCSM has been divided in the following two areas (Fig. 3):

- Area A: Disperse zone with great heterogeneity, low construction density (with irregular blocks related with its topography) and numerous green areas, which is representative of peri-urban cities. These areas are not parceled and end being occupied illegally by precariously built constructions from migrants.
- Area B: Compact zone, with a relative homogeneity and high construction density WITH orthogonal shaped blocks, which is representative of compact cities.

Regarding to their constructions CSCSM presents unfinished buildings that are mainly households owned by single families (Fig. 4). Area B is full of 3–4 storey buildings 12–16 m high that occupy their whole parcels while area A has 1–3 storey buildings (MDMQ, 2014), and parcels have lower built surfaces (Table 3).

3.2.2. Local data

Specific data are needed for the application of the present methodology in the case study, in Step 3, to determine these parameters, tomato and lettuce were selected, considering two of the most consumed vegetables in Quito and representative of Ecuadorian diet (MAGAP, 2016). They have a big difference in demand and productivity. Respective values of consumption per capita of 5.43 and 056 kg·habitant^{-1} year^{-1} were used (MAGAP, 2016). The production considered for these vegetables with Ecuador hydroponic greenhouse features, were 192,000 and 7900 kg·year^{-1} respectively (AIC, 2003; Rendón and Yance, 2012). These productions were distributed in areas A (tomatoes) and B (lettuces) in order to obtain self-sufficiency capacity of two different types of vegetables, with different performances, for all Quito's urban population. For self-supply the population of CSCSM (8862 inhabitants) was considered, (INEC, 2010). The sources used in the equations were gathered from secondary local sources, with expirience in vegetable production in traditional greenhouses (AIC, 2003; Rendón and Yance, 2012).

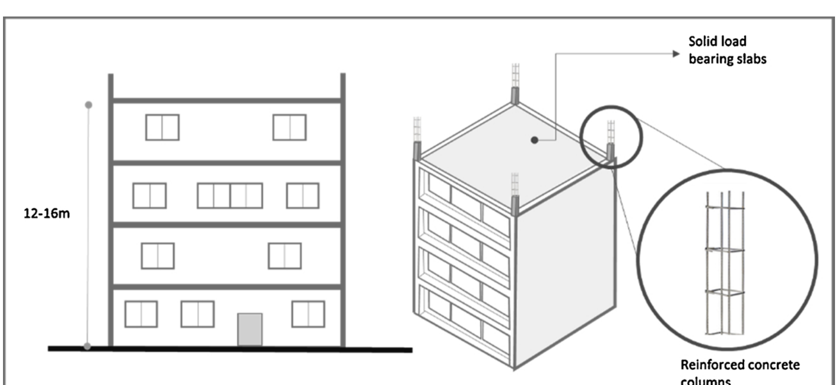


Fig. 4. Detail of unfinished housing of the CSCSM.

Table 3
CSCSM Criteria analysis.

CRITERIA	ASPECT	REQUIREMENT	RESULT	RESOURCES AND TOOLS
Urban	Legal *	Rules, ordinances, development plans and other official local documentation.	There is an ordinance related with Land Use (MDMQ, 2011a) that establishes UA as a land use. In the urban planning and construction laws attached to this ordinance, green roofs are considered and described, which not include RTGs, giving general requirements for their implementation and construction methodologies, also mentioning their classification, importance and economic and environmental benefits. Nonetheless, in this document, green roofs are considered mainly as aesthetycal features (MDMQ, 2011b). Furthermore, CSCSM has a metropolitan ordinance (MDMQ, 2014) which is a sustainable development plan for the neighborhood that includes guidelines related to land use. It establishes that all areas could apply ecological protection, which includes UA inside land use regulations.	Local official documentation. Websites of local institutions. Local cadastral plan, orthophoto. GIS
	Roof top surface available	Covers $> 10\ m^2$ Free of occupation (Antennas, water tanks, water heaters, craft workshops)	The maximum surface found in the study area was 250 m2. Studied rooftops were between this minimum and maximum surface values and classified in the three following categories: 10-90, 90-170 and 170-250 m2, the selected ranges were applied to have similar intervals between them.	
Agronomical	Social *	Agricultural Tradition and previous knowledge	The CSCSM has 35% of rural origin population (INEC, 2010; Larrea et al., 2009; MDMQ, 2011b) with experience on agriculture practices that will improve RTGs implementation results. In addition, in the CSCSM, urban orchards were found, which are mainly focused in self-consumption.	Historical Documents and Data about rurality migraton living in the area, interviews.
	Sunlight availability **	Minimum: 4-6 hours of sunlight	Sunlight hours in Quito vary little during the year because it is located close to Ecuadorian meridian. To obtain this data the Atmospheric Science Data Center was used (NASA, 2016), and an availability of 121 sunlight hours per day during all year, without seasonal differences was found, which covers the requirement of between 4 and 6 sunlight hours for UA (FAO, 2003).	Local secondary information. NASA Surface meteorology and solar energy (web application)
Technical	Architectural * Rooftop Material*	Load Capacity Reinforced concrete Metal Asbestos Zinc Roof tile Palm or straw	Reinforced Concrete (RC) in Ecuador have a load capacity of minimum 200 Kg/cm (MIDUVI, 2014), Quito buildings have RC columns and solid load bearing slabs with masonry non-load bearing facades. Most roofs, about 75 %, are RC slabs without any other material or layer on top. These roofs lack finishing, waterproof or insulation layers. The rest of roofs have metallic, asbestos cement or zinc finishing layers leaning on a light structure of steel or timber joists and beams (INEC, 2010). Older buildings have load bearing rammed earth walls and pitched roofs with light joists and beams covered with roof tiles.	Orthophoto or site inspection. GIS Orthophoto or site inspection. GIS
	Slope*	Flat Inclined Gabled Hipped Convex		Orthophoto or site inspection. GIS

3.3. Results of the case study

3.3.1. Quantification of the potential area for RTG

Step 1: Characterization based on criteria. Regarding legal background, in Ecuador there is the National plan of good living 2013–2017 (SENPLADES, 2013), which consists in national guidelines for public affairs. This plan aims to promote, develop, guarantee and transversalize social cohesion, and local and national environmental sustainability. However, the Agriculture and Environmental Ministries do not include UA in their plans. Moreover, Environmental Ministry activities catalog to get environmental licenses does neither include nor standardizes UA activities.

On the other hand, in Quito, UA is included in municipal planning as an objective (MDMQ, 2012a) and guidelines for performing it are specified in the Urban planning and construction law (MDMQ, 2011). Fresh food production is regulated by an Agriculture Ministry agency (AGROCALIDAD) and by Ecuadorian Institute of Normalization (INEN) which establish law for vegetable production, packaging and all measures needed from distribution to sale (AGROCALIDAD, 2013; INEN, 2011, 1996). Besides, there is a guideline for good practices specific for tomato cultivation (AGROCALIDAD, 2015).

CSCSM differs from other neighborhoods because it is led by a council composed of five members, which control activities and relations with external stakeholders. This council is elected each year by CSCSM households' owners. This is an advantage to apply a new experience such as RTGs, because the implementation process would be done supported by the neighborhood owners' representatives.

Finally, Quito has an ongoing experience in UA, primarily incentivized by AGRUPAR project, which assembles urban farmers and 380 communitarian organizations who work in UAs, and is supported by NGOs, Quito's municipality and universities (Duenas, 2010). This project has promoted commercialization of products holding fairs called "*bioferias*", to attract consumers with organic and urban soil agriculture products. It started to incentivize the use of balconies and rooftops in zones without access to soil, promoting vertical UA in Quito, using recycled materials (FAO, 2014b).

Step 2: Available surface determination. First data was gathered from Quito municipality dependencies. Then base geographical data was obtained from the Secretary of Territory, Habitat and Dwelling (MDMQ, 2012b) to delimit the CSCSM and it was contrasted with data included in its especial development plan (MDMQ, 2014). Ortophotos on scale 1:5000 obtained from Agriculture Ministry (SIGTIERRAS, 2016), satellite images gathered from Google™Earth were processed with ARCMAP 10.2 (ESRI, 2013).

All rooftops were identified in the aforementioned two groups: 1) short-term feasibility and 2) medium and long-term feasibility (Fig. 5). In CSCSM 3494 rooftops were found, from which 1160 were short-term feasibility (33.2%).

Through digitalization each polygon surface was measured and the total surface available for RTGs implementation was 7.70 ha (4.11 in Area A and 3.59 in Area B). Most rooftops found were between 10 and 90 m^2 (76%) and only a small amount were between 170 and 250 m^2 (3%) (Fig. 6).

Step 3: Production, self-sufficiency and self-supply. The data obtained was studied along with results from the previous step for available surfaces in the studied area and analyzed in Eqs (1), (2) and (3). Results showed that available surface for RTGs implementation, would produce 789,750 kg of tomato in area A and 28,360 kg of lettuce in area B (Eq. (1)). This production would satisfy 145,408 and 50,642 inhabitants demand respectively, roughly 9 and 4.5% of Quito's population (Eq. (2)).

As expected from results obtained for self-sufficiency, the required surface to achieve self-supply for CSCSM would be only 0.25 ha in area A for tomato and 0.61 ha in area B for lettuce, which represented 3.25 and 8.16% of available surface for short-term feasibility for RTGs implementation, in each respective area (Eq. (3)). Afterwards, the surface needed for self-supply was compared with available surface for the three ranges used, showing that from 10 to 170 m^2 would self-supply tomato and lettuce for the neighborhood but the 170-250 m^2 range would only achieve self-supply of tomato (Table 4).

Self-sufficiency equation showed that the study area would cover 9% and 4.5% of Quito's demand of tomato and lettuce respectively, which shows the big potential of RTGs implementation because CSCSM represents only the 0.17% of Quito's area (INEC, 2010; MDMQ, 2012b). Results showed that only 5.8% and 14.6% of surface of the first range of available rooftops, 10 to 90 m^2, would be required to self-supply CSCSM (Table 5). This presents an opportunity for using all other available area to produce other vegetables demanded for CSCSM residents, which could be cover with the remaining surface, and perhaps surplus for commercialization could also be obtained. If the previous case is demonstrated, the self-supply production could be focused in the first range (10-90 m^2), while surplus production could be cropped as monoculture in medium and bigger range surfaces (90-250 m^2). Commercialization would be done using the existing structure in Quito for UA products.

4. Discussion

Methodology for agricultural production on residential roofs.

The presented methodology turns out to be a tool with great potential in the residential urban contexts in comparison with those developed by Nadal et al. (2017)and Sanyé-Mengual et al. (2015a), because these focus in urban industrial contexts.

Specifically, the modifications were: 1) In the legal background, institutional review was included, to assess possibilities of institutional support on a future RTGs implementation 2) the size of rooftops found in the study area were shorter than the value of 500 m2 determined as feasible in the followed guidelines, therefore, new considerations were necessary to classify them, thus considering a minimum surface based on self-supply capacity at household level was chosen. 3) Despite the base guidelines mentioned sunlight influence in RTGs implementation, related to crop growing capacity, a measure methodology was not mentioned, in this sense, in the proposed guidelines, sunlight determination was included to know sunlight hours available in any location. 4) An equation to measure the self-supply capacity for the study area, which gives a focus to social characteristics and to food security in social neighborhoods.

These modifications contribute a more domestic or residential character, that although they bring urban agriculture closer to citizens, it represents a challenge in terms of the necessary infrastructure to be able to build a greenhouse on the roof; Both Sanjuan-Delmás et al. (2018)and Sanyé-Mengual et al. (2015a, 2015b) point out the steel structure of the greenhouse was the main contributor to environmental impact due to a large design that meets safety standards. In addition, Piezer et al.(2019)indicates that the manufacturing process is the main consumer of fossil fuels and represents 69% of the net energy input; and, it is necessary to carry out an analysis of the life cycle evaluating different alternatives of structures, both metallic and other materials, considering the height conditions of the houses, the complete life cycle of the material and the specific conditions of the local context.

In this line, Cerón-Palma et al. (2013) explored the implementation of rooftop greenhouses in homes of the Yucatan Peninsula in Mexico as a strategy to reduce energy consumption and GHG emissions, obtaining savings of 391 kgCO2eq / year per house, in addition to offering environmental, economic and social benefits, coinciding with the present study. Regarding the environmental benefits that rooftop greenhouses provide to residential neighborhoods, it is worth mentioning the decrease in indoor temperatures, as indicated by Peng and Jim (2013)and Doshi (2006), which in the case of cities with high temperatures turn out to be a strategy with great potential, as is the case of Quito.

Also, the culture of saving drinking water would be favored widely in Latin America, since the system of cultivation of hydroponics allows

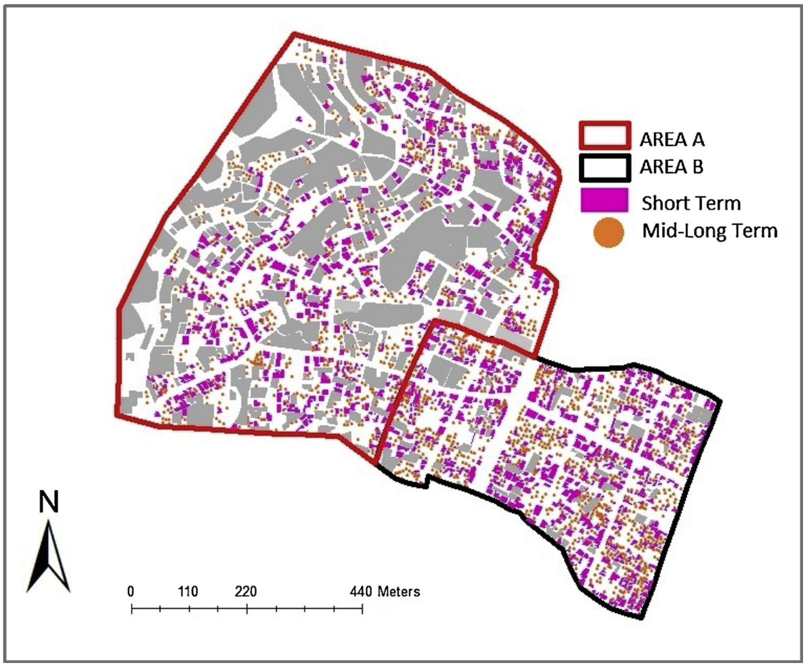


Fig. 5. Characterization of covers in CSCSM.

an efficient and quality use of water for irrigation, in addition to the greenhouses on the roof promote the collection of rainwater for the irrigation of crops. This would mean an economic saving and a lower environmental impact than the use of drinking water, as Sanjuan-Delmás et al. (2018)and Farreny et al. (2011)points out. Finally, a highlight of the presented methodology is the ability to adapt to different contexts, through consultation with local sources of information, information on weather conditions, local crops, among others; and in this way serve as a basis for future interventions in cities around the world.

Potential of rooftops in Quito.

The selected study area combined characteristics representative of both urban and periurban territories. It was useful to test the guidelines in both urban configurations (high building density, Area B) and periurban configuration (middle building density, area A). The results obtained using the guidelines validate their application, even though, some further verification may be required in similar studies due to differences in the quality of existing data with those of the chosen study area.

Most rooftops had a surface between 10-90 m^2 while the maximum surface was 250 m^2. This important difference is remarkable, but the main criterion considered in this analysis, focused on a social neighborhood, was self-supply capacity rather than economic threshold. Medium and long-term feasibile rooftops are not considered, because in the case of a social neighborhood extra expenses (constructions adaptations) that would be caused to dwellers could prevent the RTGs implementation to fulfil the chosen social approach. Only 33.2% of rooftops were short-term feasibility, a value much lower than the expected one of 75%, which is the proportion of RC rooftops found in the neighborhood in the Ecuadorian census of 2010 (INEC, 2010). This showed the importance of performing a research in neighborhood scale, because results could vary from general statistics for city level. The results for self-supply showed that there is a potential to produce more vegetables demanded in the neighborhood, which would allow to persue food security inside the neighborhood.

However, it would be necessary to carry out studies on the quality of the products, in order to guarantee that these are free of atmospheric and aerobiological contaminants such as those made by (Amato-Lourenco et al., 2016) and Ercilla-Montserrat et al. (2018, 2017), in the Mediterranean context. Another question to consider for 75% of the roofs with medium or long-term potential is the fact of including the green roof strategy, since as Zhao et al. (2015) and Mohajerani et al. (2017) point out, this modification generates great thermal advantages inside the homes, over all in cities with high temperatures like Quito. At the same time, one could also explore more complex and multifunctional systems such as rainwater harvesting or the use of photovoltaic cells to capture energy, creating a mosaic of productive rooftops as proposed by Toboso-Chavero et al.(2018).

5. Conclusions

This methodology has proven to be a promising and adaptable tool for identifying all rooftops with the potential for the implementation of RTGs with a social and residential perspective. The main strengths of the proposed methodology are based on the use of GIS and urban, agronomic and technical criteria; In addition to considering the demand for food, the size of the population to calculate self-sufficiency and self-supply in the short, medium and long term. However, field visits are necessary for the confirmation of information.

These guidelines can be useful for Latin American decision makers, researchers, students, communitarian organizations, schools, universities and local governments among others. These parties could assess their own RTGs initiatives adapting the guidelines to their goals. This would allow to create opportunities and to project the future of the cities with a self-supply perspective that would improve city resilience.

For this research, in the study area there were found a total of 3.494 rooftops, from which 1.160 (33.2%) were considered as short-term feasibility. There were obtained a surface of 7.70 ha (around the 12% of the study area surface) of short-term feasibility rooftops. Regarding self-sufficiency and self-supply, study area would supply the 9% and 4.5% of Quito's demand of tomato and lettuce; and in a neighborhood scale 100% self-sufficiency and self-supply was obtained. The above supports

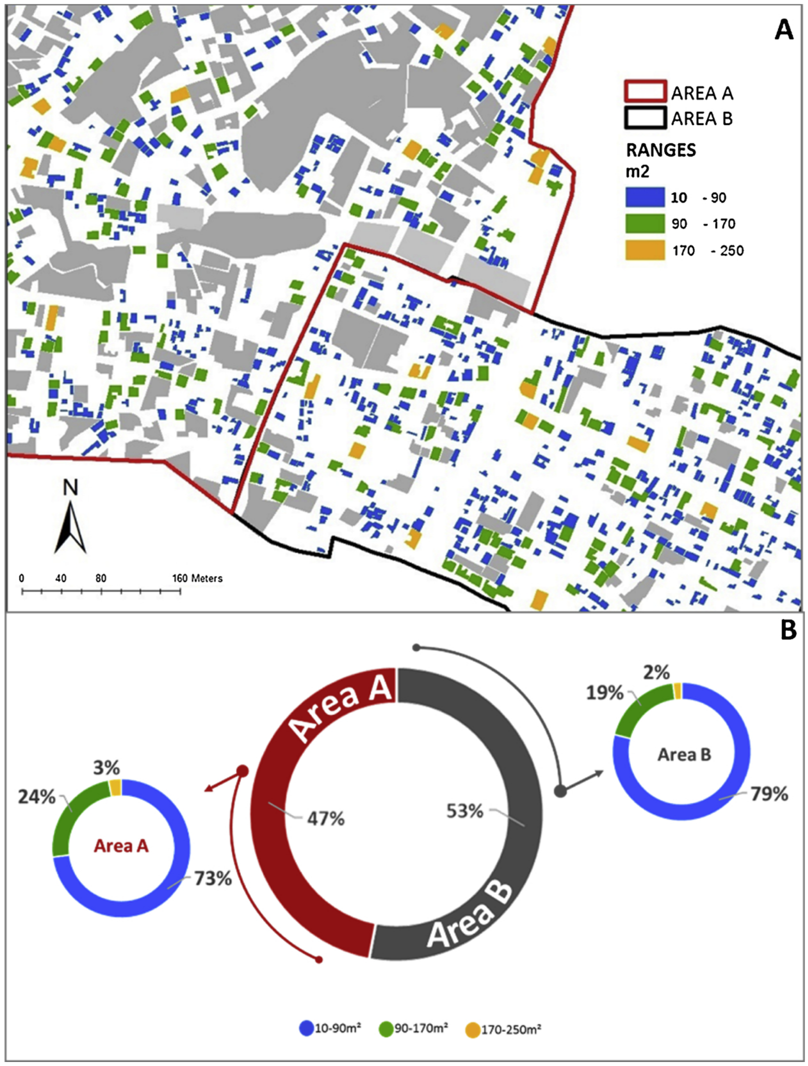


Fig. 6. A.Ranges of short term available surfaces in CSCSM by ranges. B.Percentages of available surfaces per range for short term implementation of RTGs.

Table 4
Potential Production and Self-Sufficiency for CSCSM short-term feasibility RTGs implementation.

	Area A (Tomato)			Area B (Lettuce)		
Surface Ranges (m^2)	**10-90**	**90-170**	**170-250**	**10-90**	**90-170**	**170-250**
Short-term available surface (ha)	2,16	1,64	0,32	2,14	1,23	0,22
“PR” Potential Production (kg/year)	413,900	315,000	60,700	16,91	9,75	1,70
	7,895,700			28,36		
“SS” Self-sufficiency (Inhabitant)	76226	58011	11170	30194	17415	3033
	145408			50642		

Note: Tomato performance is 192,000 kg/ha/year (AIC, 2003),lettuce performance is 7900 kg/ha/year (Rendón and Ledesma,2012), demand of tomato is 543 kg/person/year, and of lettuce is 056 kg/person/year (this is consider for an adult consume, the only data available) (MAGAP, 2016).

the effectiveness and potential use of the proposed methodology. This methodology also provides the opportunity to provide a new character and activity to the roofs and the unfinished houses, taking advantage of it effectively and providing a real and efficient alternative for the residual and unused spaces, such as a large part of the roofs in Quito.

In addition to the direct benefits at the level of nutrition derived from the cultivation in the roofs, the benefits at environmental and urban level that can be generated can also be considered. Regarding future work, the present study opens the door to new lines of research in the field of urban food systems; it is necessary to study the impact and feasibility of using different local substrates for the production of horticultural crops on the roofs, as well as the analysis of various materials for the structure of the greenhouses; and at the food level, it would be interesting to evaluate the quality of the products produced by protected (with greenhouses) and unprotected (without greenhouses) crops in urban areas.

Table 5
Required surface for self-supply of CSCSM.

Self-Supply required area (ha)				
Vegetable			Tomato %	Lettuce %
"SPA" (*ha*)			*0,25*	*0,63*
Short-term available surface by ranges (*ha*)	***10-90***	*4,3*	5,83	14,61
	90-170	*2,87*	8,73	7,19
	170-250	*0,54*	46,41	100*
Percentage needed of Total available surface			***3,25***	***8,16***

Note: Population CSCSM: 8862 inhabitants; "SPA" Self-supply required area, Short-term available surface by ranges: 7,7 ha.
* Characterized area is lower than required area.

Acknowledgments

The authors thank the Spanish Ministry of Economy and Competitiveness (MINECO) for the financial support for the research project “Agrourban sustainability through rooftop greenhouses. Eco-innovation on residual flows of energy, water and CO2 for food production” (CTM2013-47067-C2-1-R) (MINECO/ FEDER, UE) and the research project “Integrated rooftop greenhouses: a symbiosis of energy, water and CO2 emissions for buildings. Towards urban food security in a circular economy” CTM2016-75772-C3-1-2-3 R) (MINECO/ FEDER, UE). The authors also acknowledge financial support from the Spanish Ministry of Economy and Competitiveness through the “María de Maeztu” program for Units of Excellence in R&D (MDM-2015-0552), the National Council for Science and Technology of Mexico (CONACYT), the Council for Science, Innovation and Technology of State of Yucatán (CONCIYTEY) for awarding a research scholarship to Ana Nadal (CV376044), and to the Ecuadorian Secretary for Science and Technology (SENESCYT) for the scholarship granted to D. Rodriguez in Convocatoria Abierta 2015 s phase.

Appendix A. Main characteristics of Quito metropolitan district

Characteristic	Value	Reference
Altitude range	1200-4000 mamsl	EPM-METROQUITO, 2012, MDMQ, 2012a, 2012
Precipitation in dry season (June to September)	202 to 27 mm/month	(INAMHI, 2015)
Precipitation in rainy season (October to May)	1262 to 1622 mm/month	INAMHI, 2015
Climate zones	15 (Holdridge map)	EPM-METROQUITO, 2012
Temperature range	(-4 C to 22 °C)	INAMHI, 2015
Average temperature in the urban area	16 °C	MDMQ, 2012a, 2012
Urban population	1,6 millions	INEC, 2010
Annual growth index	1,5%	INEC, 2010
Population density	92 inhabitants/ha	INEC, 2010
Rooftop composition	75, 32% reinforced concrete 2468% others	INEC, 2010

Appendix B. Socio-economic indicators of the study area

Indicator	Value	Reference
Population	8862 inhabitants	INEC, 2010; MDMQ, 2011
Surface	63.29 ha	INEC, 2010; MDMQ, 2011
Housing built	3,490	INEC, 2010; MDMQ, 2011
Population density	110.5 inhabitants/ha	INEC, 2010; MDMQ, 2011
Population men	4,273 inhabitants	INEC, 2010; MDMQ, 2011
Population women	4,589 inhabitants	INEC, 2010; MDMQ, 2011
Population under 5 years	366 inhabitants	INEC, 2010; MDMQ, 2011
Economically active population	6,080 inhabitants	INEC, 2010; MDMQ, 2011
Unemployment rate	3.8%	Larrea, 2009
Chronically undernourished children	32.4% - 35.3%	Larrea, 2009

References

AGROCALIDAD, 2015. Resolución Técnica N - 0105. Guía de buenas práctivas agrícolas para tomate riñón.
AGROCALIDAD, 2013. Resolución DAJ-2013465-0201.0226 Manual de Procedimiento para la Certificación de Unidades de Producción de Buenas Prácticas Agrícolas Generales.
AIC, 2003. El Cultivo De Tomate Rinon En Invernadero Lycopersicum Esculentum. Asociacion de Indígenas del Cañar, Quito, Ecuador.
Amato-Lourenco, L.F., Moreira, T.C.L., De Oliveira Souza, V.C., Barbosa, F., Saiki, M., Saldiva, P.H.N., Mauad, T., 2016. The influence of atmospheric particles on the elemental content of vegetables in urban gardens of Sao Paulo, Brazil. Environ. Pollut. 216, 125–134. https://doi.org/10.1016/j.envpol.2016.05.036.
Baker, L., 2000. Warehouse supports Urban agriculture. Bussiness, vol. 22. pp. 16–18.
Baudoin, W., Nono-Womdim, R., Lutaladio, N., Hodder, A., Castilla, N., Leonardi, C., De Pascale, S., Qaryouti, M., 2013. Good Agricultural Practices for Greenhouse Vegetable Crops: Principles for Mediterranean Climate Areas. Food and Agriculture Organization of the United Nations.
Carrión, F., Erazo, J., 2012. La forma urbana de Quito: una historia de centros y periferias. Bull. l'Institut français d'études Andin. 503–522. https://doi.org/10.4000/bifea.361.
Cerón-Palma, I., Sanyé-Mengual, E., Oliver-Solà, J., Montero, J.-I., Rieradevall, J., 2012. Barriers and opportunities regarding the implementation of Rooftop Eco.GReenhouses (RTEG) in Mediterranean cities of Europe. J. Urban Technol. 19, 1–17. https://doi.org/10.1080/10630732.2012.717685.
Cerón-Palma, I., Sanyé-Mengual, E., Oliver-Solà, J., Montero, J.I., Ponce-Caballero, C., Rieradevall, J., 2013. Towards a green sustainable strategy for social neighbourhoods in Latin America: Case from social housing in Merida, Yucatan, Mexico. Habitat Int. 38, 47–56. https://doi.org/10.1016/j.habitatint.2012.09.008.
Chavoya, I., García, J., Rendón, H., 2009. Una reflexión sobre el modelo urbano: ciudad dispersa-ciudad compacta. SCTV Barcelona. pp. 37–50.
Clavijo, C., 2013. La agricultura urbana en Quito: análisis de la sustentabilidad de las huertas de tres proyectos.
Colinas, J., Bush, P., Manaugh, K., 2018. The Socio-Environmental Impacts of Public Urban Fruit Trees: A Montreal Case-study. Urban For. Urban Greenhttps://doi.org/10.1016/j.ufug.2018.05.002.
CONQUITO, 2009. La ciudad viva como URBS, Agencia Municipal de Desarrollo Económico - CONQUITO. Congreso Internacional: La Ciudad Viva Como URBS. Agricultura Urbana Participativa AGRUPAR - Quito, Ecuador, pp. 1–9.
Correa, F., 2012. Una linea en los Andes. GSD-Harvard, Cambridge.
Cruz, M.C., Sánchez-Medina, R., 2003. Agriculture in the City. A Key to Sustainability in Havana, Cuba, Idrc.

De la Sota, C., Ruffato-Ferreira, V.J., Ruiz-García, L., Alvarez, S., 2018. Urban Green Infrastructure As a Strategy of Climate Change Mitigation. A Case Study in Northern Spain. Urban For. Urban Greenhttps://doi.org/10.1016/j.ufug.2018.09.004.
Despommier, D., 2011. The vertical farm. HortScience.
Doshi, H., 2006. Environmental benefits of Green roofs on a City scale—an example of City of Toronto. 4th North American Green Roof Conference: Greening Rooftops for Sustainable Communities.
Dubbeling, M., Massonneau, E., 2014. Rooftop agriculture in the context of climate change. Appropriate Technology 41 (3), 48–52.
Duenas, A.R., 2010. Promoting value chains in urban agriculture for local development in Quito. Urban Agric. Mag. 61–62.
Empresa Pública Metropolitana METRO QUITO, 2012. Estudio de Impacto Ambiental de la Primera Línea del Metro de Quito. 322.
Ercilla-Montserrat, M., Izquierdo, R., Belmonte, J., Montero, J.I., Muñoz, P., De Linares, C., Rieradevall, J., 2017. Building-integrated agriculture: A first assessment of aerobiological air quality in rooftop greenhouses (i-RTGs). Sci. Total Environ. https://doi.org/10.1016/j.scitotenv.2017.04.099.
Ercilla-Montserrat, M., Muñoz, P., Montero, J.I., Gabarrell, X., Rieradevall, J., 2018. A study on air quality and heavy metals content of urban food produced in a Mediterranean city (Barcelona). J. Clean. Prod. https://doi.org/10.1016/j.jclepro.2018.05.183.
ESRI, 2013. ARCMAP 10.2.
FAO, 2014a. City Region Food Systems: Sustainable Food Syst Ems and Urbanization.
FAO, 2014b. Ciudades más verdes en América Latina y el Caribe. Un informe de la FAO sobre la agricultura urbana y periurbana en la región, Roma, Italia.
FAO, 2012. Agricultura Urbana y periurbana en América Latina y El Caribe : una realidad. Roma, Italia. .
FAO, 2005. Los Medios de vida Crecen en los Huertos. Roma, Italia. .
Farreny, R., Morales-Pinzón, T., Guisasola, A., Tayà, C., Rieradevall, J., Gabarrell, X., 2011. Roof selection for rainwater harvesting: quantity and quality assessments in Spain. Water Res. 45, 3245–3254. https://doi.org/10.1016/j.watres.2011.03.036.
Figueroa, J.A., 2012. Nono Movilización Política y migración campesina, 1st ed. Municipio del Distrito Metropolitano de Quito, Quito, Ecuador.
Garza, N., 2009. Urban economic-environmental dilemas in Latin American cities Néstor Garza. Investig. y Desarro. 17, 288–328.
Germer, J., Sauerborn, J., Asch, F., de Boer, J., Schreiber, J., Weber, G., Müller, J., 2011. Skyfarming an ecological innovation to enhance global food security. J. Fur Verbraucherschutz und Leb. 6, 237–251. https://doi.org/10.1007/s00003-011-0691-6.
Gilbert, A., 2011. La vivienda en américa latina: revisando estrategias. Rev. Ing.
Halloran, A., 2011. Incorporating Urban Agriculture Into Urban Planning : the Tale of Three Cities. Copenhagen, Denmark. .
Hou, J., Grohmann, D., 2018. Integrating community gardens into urban parks: lessons in planning, design and partnership from Seattle. Urban For. Urban Green. https://doi.org/10.1016/j.ufug.2018.05.007.
INAMHI, 2015a. Boletín climatológico Semestral 2015 - 001 - Instituto de Meteorología e Hidrología. Quito, Ecuador. .
INAMHI, I.D.M.E.H., 2015b. Boletín climatológico SEMESTRAL 1015. Vol. 01.
INEC, 2010. Sistema Integrado de Consultas (REDATAM) - Instituto Naciona de Estadísticas y Censos del Ecuador [WWW Document]. VII Censo Población y VI vivienda.
INEN, 2011. NTE INEN 1334-1:2011 Rotulado de productos alimenticios para consumo humano. Parte 1. Requisitos.
INEN, 1996. NTE INEN 2 104:1996 Hortalizas frescas. Definiciones y Clasificación.
Jaramillo, E., Van Sluys, C., 2012. Repensar el proyecto urbano residencial en la ciudad lineal: Un estudio urbano arquitectonico sobre la vivienda sustentable en el distrito metropolitano de Quito. I Congreso Internacional de Vivienda Colectiva Sostenible, Barcelona, 25, 26 y 27 de Febrero de 2014. pp. 354–359.
Jeavons, J., Cox, C., 2007. El huerto sustentable, como obtener suelos saludables, productos sanos y abundantes. Universidad de California.
Larrea, C., Larrea, A.I., Andrade, D., 2009. Atlas Social Para Quito Urbano.
La Rosa, D., Barbarossa, L., Privitera, R., Martinico, F., 2014. Agriculture and the city: a method for sustainable planning of new forms of agriculture in urban contexts. Land Use Policy 41, 290–303. https://doi.org/10.1016/j.landusepol.2014.06.014.
MAGAP, 2016. Sistema de Informacion Nacional del Ministerio de Agricultura Ganaderia y Pesca del Ecuador [WWW Document].
Maxwell, D., 2000. Urban Livelihoods and Food and Nutrition Security in Greater Accra, Ghana, Research Report 112. International Food Policy Research Institute in collaboration with Noguchi Memorial Institute for Medical Research and the World Health Organization, Washington, D.C 2000, pp. xiv, 172.
Maxwell, D., Larbi, W.O., Lamptey, G.M., Zakariah, S., Armar-Klemesu, M., 1999. Farming in the shadow of the city: changes in land rights and livelihoods in periurban Accra. Third World Plann. Rev. 21, 373–392.
MDMQ, 2014. Ordenanza Municipal 0024: Plan Especial De Desarrollo Territorial Comuna Santa Clara De San Millán - Distrito Metropolitano De Quito.
MDMQ, 2012a. Plan Metropolitano de Ordenamiento Territorial - Municipio del Distrito Metropolitano de Quito.
MDMQ, 2012b. Secretaria de Territorio Habitat y Vivienda - Municipio del Distrito Metropolitano de Quito [WWW Document].
MDMQ, 2011. Reglas Técnicas de Arquitectura y Urbanismo (Anexo de la Oordenanza Municipal 172 Del Régimen Administrativo del Suelo) - Municipio del Distrito Metropolitano de Quito.
Mohajerani, A., Bakaric, J., Jeffrey-Bailey, T., 2017. The urban heat island effect, its causes, and mitigation, with reference to the thermal properties of asphalt concrete. J. Environ. Manage. https://doi.org/10.1016/j.jenvman.2017.03.095.
Montero, J.I., Muñoz, P., Llorach, P., Nadal, A., Sanyé-Mengual, E., Rieradevall, J., 2017. Development of a building-integrated roof top greenhouse in Barcelona, Spain. Acta Hortic. https://doi.org/10.17660/ActaHortic.2017.1170.107.
Moran-Alonso, N., 2011. Huertos urbanos en tres ciudades europeas: Londres, Berlín, Madrid. Boletín CF+ S 2008–2009. https://doi.org/1578-097X.
Moran-Alonso, N., Hernandez, A., 2011. Historia de los huertos urbanos. De los huertos pobres a los programas de agircultura urbana ecoló gica, Programas De Agricultura Urbana Ecológica, Madrid.
Nadal, A., Alamús, R., Pipia, L., Ruiz, A., Corbera, J., Cuerva, E., Rieradevall, J., Josa, A., 2017a. Urban planning and agriculture. Methodology for assessing rooftop greenhouse potential of non-residential areas using airborne sensors. Sci. Total Environ. 601–602. https://doi.org/10.1016/j.scitotenv.2017.03.214.
Nadal, A., Cerón-Palma, I., García-Gómez, C., Pérez-Sánchez, M., Rodríguez-Labajos, B., Cuerva, E., Josa, A., Rieradevall, J., 2018. Social perception of urban agriculture in Latin-America. A case study in Mexican social housing. Land Use Policy. https://doi.org/10.1016/j.landusepol.2018.02.055.
Nadal, A., Cerón, I., Cuerva, E., Gabarrell, X., Josa, A., Pons, O., Sanyé, E., Rieradevall, J., 2015. Urban agriculture in the framework of sustainable urbanism. Temes de disseny 0, 92–103.
Nadal, A., Llorach-Massana, P., Cuerva, E., López-Capel, E., Montero, J.I., Josa, A., Rieradevall, J., Royapoor, M., 2017. Building-integrated rooftop greenhouses: an energy and environmental assessment in the mediterranean context. Appl. Energy 187, 338–351. https://doi.org/10.1016/j.apenergy.2016.11.051.
Nadal, A., Llorach-Massana, P., Cuerva, E., López-Capel, E., Montero, J.I., Josa, A., Rieradevall, J., Royapoor, M., 2017b. Building-integrated rooftop greenhouses: an energy and environmental assessment in the mediterranean context. Appl. Energy 187. https://doi.org/10.1016/j.apenergy.2016.11.051.
Nastran, M., Kobal, M., Eler, K., 2019. Urban heat islands in relation to green land use in European cities. Urban For. Urban Green. https://doi.org/10.1016/j.ufug.2018.01.008.
Nieto, M., 1999. Metodología de evaluación de proyectos de viviendas sociales.
NU. CEPAL, 2013. Estrategias de desarrollo bajo en carbono en megaciudades de América Latina. Santiago, Chile. .
Orsini, F., Gasperi, D., Marchetti, L., Piovene, C., Draghetti, S., Ramazzotti, S., Bazzocchi, G., Gianquinto, G., 2014. Exploring the production capacity of rooftop gardens (RTGs) in urban agriculture: the potential impact on food and nutrition security, biodiversity and other ecosystem services in the city of Bologna. Food Secur. 6, 781–792. https://doi.org/10.1007/s12571-014-0389-6.
Orsini, F., Kahane, R., Nono-Womdim, R., Gianquinto, G., 2013. Urban agriculture in the developing world: a review. Agron. Sustain. Dev. https://doi.org/10.1007/s13593-013-0143-z.
Peng, L.L.H., Jim, C.Y., 2013. Green-roof effects on neighborhood microclimate and human thermal sensation. Energies 6, 598–618. https://doi.org/10.3390/en6020598.
Piezer, K., Petit-Boix, A., Sanjuan-Delmás, D., Briese, E., Celik, I., Rieradevall, J., Gabarrell, X., Josa, A., Apul, D., 2019. Ecological network analysis of growing tomatoes in an urban rooftop greenhouse. Sci. Total Environ. https://doi.org/10.1016/j.scitotenv.2018.09.293.
Pons, O., Nadal, A., Sanyé-Mengual, E., Llorach-Massana, P., Cuerva, E., Sanjuan-Delmás, D., Muñoz, P., Oliver-Solá, J., Planas, C., Rovira, M.R., 2015. Roofs of the future: rooftop greenhouses to improve buildings metabolism. Procedia Engineering 441–448. https://doi.org/10.1016/j.proeng.2015.10.084.
Quintero, M., Gómez, L., 2012. ciudades difusas a ciudades compactas. Provincia 27, 43–76.
Rendón, V., Yance, M., 2012. Establecimiento del cultivo hidropónico de Lechuga (Lactuca sativa L.) variedad Great Lakes 188, mediante la utilización de diferentes tipos de sustratos sólidos en la zona de Babahoyo. Universidad Técnica de Babahoyohttps://doi.org/10.1017/CBO9781107415324.004.
Rojas, E., 2016. Housing policies and Urban development: lessons from the latin American experience 1960-2010. Land and the City. p. 429.
RUAF Foundation, 2015. City Region Food Systems. Urban Agric. Mag.
Sanjuan-Delmás, D., Llorach-Massana, P., Nadal, A., Ercilla-Montserrat, M., Muñoz, P., Montero, J.I., Josa, A., Gabarrell, X., Rieradevall, J., 2018. Environmental assessment of an integrated rooftop greenhouse for food production in cities. J. Clean. Prod. 177, 326–337. https://doi.org/10.1016/j.jclepro.2017.12.147.
Sanyé-Mengual, E., Cerón-Palma, I., Oliver-Solà, J., Montero, J.I., Rieradevall, J., 2015a. Integrating horticulture into cities: a guide for assessing the implementation potential of rooftop greenhouses (RTGs) in industrial and logistics parks. J. Urban Technol. 22, 87–111. https://doi.org/10.1080/10630732.2014.942095.
Sanyé-Mengual, E., Oliver-Solà, J., Montero, J.I., Rieradevall, J., 2015b. An environmental and economic life cycle assessment of rooftop greenhouse (RTG) implementation in Barcelona, Spain. Assessing new forms of urban agriculture from the greenhouse structure to the final product level. Int. J. Life Cycle Assess. 20, 350–366. https://doi.org/10.1007/s11367-014-0836-9.
Schneider, A., Woodcock, C.E., 2008. Compact, dispersed, fragmented, extensive? A comparison of urban growth in twenty-five global cities using remotely sensed data, pattern metrics and census information. Urban Stud. https://doi.org/10.1177/0042098007087340.
SENPLADES, 2013. Plan Nacional Buen Vivir 2013-2017. Secretaría Nacional de Planificación y Desarrollo.
SIGTIERRAS, 2016. Fotografía Area y Ortofotos. [WWW Document]. .
Tian, Y., Jim, C.Y., Tao, Y., 2012. Challenges and strategies for greening the compact city of Hong Kong. J. Urban Plan. Dev. https://doi.org/10.1061/(ASCE)UP.1943-5444.0000076.
Toboso-Chavero, S., Nadal, A., Petit-Boix, A., Pons, O., Villalba, G., Gabarrell, X., Josa, A., Rieradevall, J., 2018. Towards productive cities: environmental assessment of the food-energy-Water Nexus of the urban roof mosaic. J. Ind. Ecol. 22, 14. https://doi.

org/10.1111/jiec.12829.
Vaca, F., 2015. El perfil vertical. Plan V Miradas.
Wadel, G., Avellaneda, A., Cuchí, A., 2010. Sustainability in industrialised architecture: closing the materials cycle [La sostenibilidad en la arquitectura industrializada: cerrando el ciclo de los materiales]. Inf. la Constr. 62, 37–51. https://doi.org/10.3989/ic.09.067.
Willett, W., Rockström, J., Loken, B., Springmann, M., Lang, T., Vermeulen, S., Garnett, T., Tilman, D., DeClerck, F., Wood, A., Jonell, M., Clark, M., Gordon, L.J., Fanzo, J., Hawkes, C., Zurayk, R., Rivera, J.A., De Vries, W., Majele Sibanda, L., Afshin, A., Chaudhary, A., Herrero, M., Agustina, R., Branca, F., Lartey, A., Fan, S., Crona, B., Fox, E., Bignet, V., Troell, M., Lindahl, T., Singh, S., Cornell, S.E., Srinath Reddy, K., Narain, S., Nishtar, S., Murray, C.J.L., 2019. Food in the Anthropocene: the EAT–lancet Commission on healthy diets from sustainable food systems. Lancet. https://doi.org/10.1016/S0140-6736(18)31788-4.
Zezza, A., Tasciotti, L., 2010. Urban agriculture, poverty, and food security: empirical evidence from a sample of developing countries. Food Policy 35, 265–273. https://doi.org/10.1016/j.foodpol.2010.04.007.
Zhao, Q., Myint, S.W., Wentz, E.A., Fan, C., 2015. Rooftop surface temperature analysis in an Urban residential environment. Remote Sens. (Basel) 7, 12135–12159. https://doi.org/10.3390/rs70912135.